Gas Electron Multiplier Development Using LIGA

H.K. Kim[1,4], K.H. Jackson[2], J. Lee[3], I.J. Park[1,5], S.H. Han[1,6],
J. Kadyk[1], V. Perez-Mendez[1], W. Wenzel[1] and G. Cho[4]

[1]Physics and [2]Material Sciences, and Engineering[3] Divisions Lawrence Berkeley National Laboratory, Berkeley, CA 94720
[4]Department of Nuclear Engineering, Korea Advanced Institute of Science and Technology, Teajon 305-701, Korea
[5]Department of Physics, Myongji University, Yongin 449-728, Korea
[6]Department of Physics, Kyungpook National University, Teagu 702-701, Korea

Introduction

Since the Micro-Strip Gas Chamber (MSGC) was first introduced in 1987 [1], a large amount of effort has been invested in this new field of gas avalanche microdetectors. Improvements in and variations from the original MSGC design have led to even better detector performance. Other innovative devices have recently been produced, such as CAT [2] and the Gas Electron Multiplier (GEM) [3], using the concept of electrodes separated by an insulator between them, resulting in intense electric field across a hole defined through the insulator.

The GEM geometry has a unique advantage in that the multiplication region is separate from the readout electrodes, which, in the case of gas avalanche microdetectors (MSGC, MGC, MDOT, etc.) are usually very vulnerable to damage from sparking. However, the conventional GEM design, has a conically shaped hole in the insulating substrate (Kapton). In the case of this device, a gain variation with time is observed: there is about 10 % gain increase within 1 hour [4]. This gain shift is presumably due to the charging by avalanche ions (or electrons) of the GEM Kapton insulator. For comparison, a laser drilled GEM on 125 μm-thick polyimide foil with nearly straight walls (8° wall inclination) have been made at the University of Louisville and tested by us, and this exhibited a very stable gain (~ 1%) [4].

We have been collaborating with our colleagues in Materials Sciences Division on a new approach for fabrication of micro-pixel arrays for GEM devices with high aspect ratio wall sides. The fabrication of these GEM devices is based on LIGA processing. The acronym LIGA originates from the German expressions for the major process steps: lithography (**LI**thographie), electroplating (**G**alvanoformung) and molding (**A**bformung). The LIGA process as applied here uses X-rays of 2-15 keV energy to expose through a patterned mask a thick PMMA "resist" layer (50 - 1,000 μm).

Fabrication of GEM Pixel Arrays

We used PMMA, the most common X-ray resist in the LIGA process, as an insulator material for the LIGA device. Initially, the PMMA is in sheet form and the minimum thickness of PMMA sheet commonly available is typically 1 mm. Thinner PMMA sheets may be made by compression in a heated press, yielding reasonably good thickness uniformity and few defects.

<u>Mask preparation</u>. In our mask fabrication, a 100 μm-thick 3-inch diameter silicon wafer is used as a substrate for the thick (~ 25 μm) gold-patterned absorbers. The silicon wafer was coated with thick photoresist, and patterned by a standard photomask having a hole pattern consisting of 150 μm × 150 μm rectangular holes with a 300 μm pitch. The active area was 30 mm × 30 mm. After electroplating 25 μm-thick gold absorbers on these patterns, the photoresist was lifted off leaving the patterned gold layer.

<u>Exposure</u>. The exposure dose was determined based on simulations using CXRL toolset [5], considering all the spectral filtering effects of the synchrotron radiation beamline and intervening absorbing material. A minimum dose of 4 kJ/cm^3 is required to expose the PMMA. A typical LIGA exposure for a 300 μm-thick piece of PMMA is ~ 12 hours. Table 1 shows the dose and exposure time to be used for different thicknesses of PMMA sheets.

Thickness	Dose (kJ/cm^3)		Exposure
(μm)	Top	Bottom	(mA·min)
125	8.20	7.52	143000
350	8.20	6.92	143000
1000	12.04	6.64	210000

Table 1: Dose and exposure time for various thicknesses' PMMA sheets. Exposure was done at the ALS beamline 3.3.2 , the total dose is in mA-minutes.

PMMA Development. After exposure the PMMA is developed using a mixture of 2-2 butoxyelthoxyethanol, morpholine, ethoamine and deionized water. A Scanning Electron Microscope (SEM) photograph of the developed PMMA with a thickness of 350 μm is shown in Fig. 1. Finally, in order to form GEM-like devices, a thin (25 - 100 angstroms) chromium layer was deposited by vacuum evaporation on the top and bottom surfaces, to be used as electrodes. The LIGA device was inserted between two electrode planes, the drift and collection planes, which were spaced by 3 and 1 mm, respectively, from the LIGA device as shown in Fig. 2.

Results and Discussion

The measurements of gas avalanche gain and with respect to the applied voltage are plotted in Fig. 3. As mentioned earlier, the gain reported here is based upon the signal obtained from the MSGC anode strips only (inadvertently), and so represents a lower limit to the actual gain. The currents to the anode and cathode strips, and corresponding measured "gains" are expected to divide approximately as the ratio of strip width, cathode width / anode width = 90 μm / 10 μm = 9. The current of MSGC cathodes was also measured at the same time. The maximum avalanche gain was obtained for 350 μm-thick LIGA device running at 1,300 volts. The corresponding central field is ~ 37 kV/cm. As compared with the conventional GEM having an effective gas gain of ~ 1,000 at 500 volt per 50 μm-thick Kapton corresponding to 100 kV/cm of field strength [6], there appears to be significant improvement in gain. This improvement could be partially explained by the longer path length available for the avalanches in the multiplication region.

From the steep wall shape as well as the relatively low surface resistivity, it is expected that the loss of gain vs. event rate due to charge accumulation on insulator surface will be a small effect. Figure 4 shows the pulse height spectrum for a ^{55}Fe source obtained by the LIGA device with 350 μm thickness. The best FWHM energy resolution obtained is 17 % with 5.9 keV X-rays.

Conclusions

A new approach to make GEM-type gas avalanche microdetectors has been discussed based on the LIGA fabrication technique. The technique as described in this study has advantages in design flexibility, such as in thickness and pitch, and allows increased path length for gas avalanche

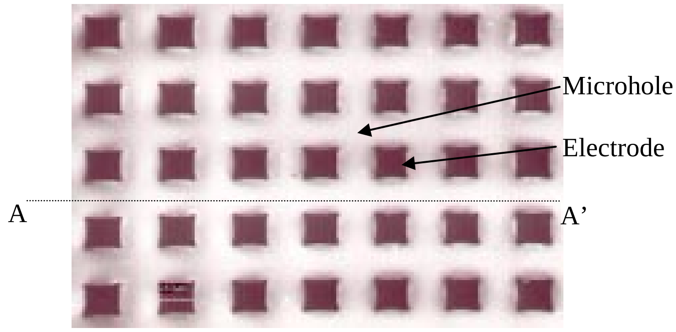

Figure 1: Scanning Electron Microscope (SEM) photograph of hole array in PMMA sheet having very steep wall sides made by LIGA process. 150 × 150 μm^2 rectangular holes with a pitch of 300 μm are patterned on a 350 μm-thick PMMA sheet.

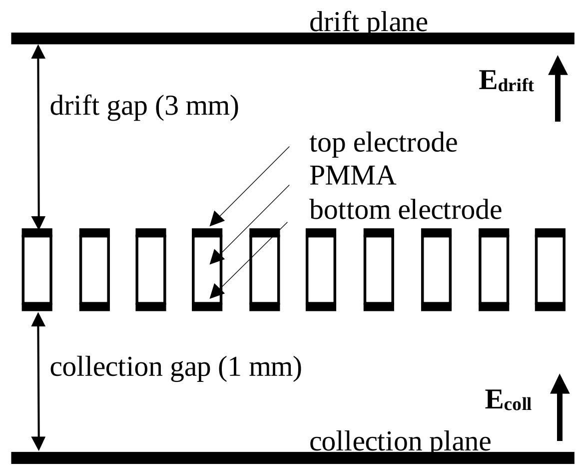

Figure 2: Schematic structure of the LIGA device (cross-section view along A-A' in Fig. 1) coupled with a plane of collection electrodes (without gain). In our tests, we used a 200 μm pitch MSGC for the collection electrodes.

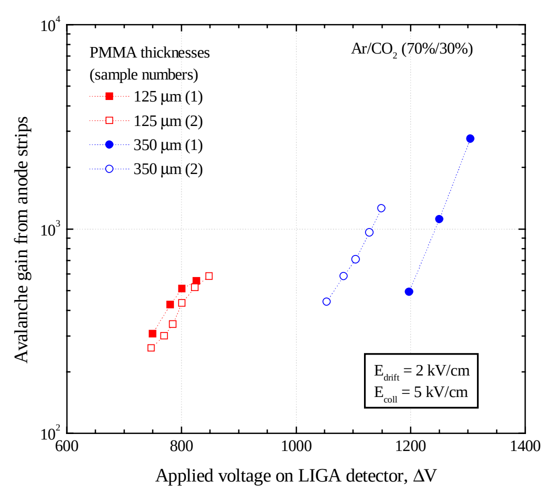

Figure 3: Measurements of avalanche gain as measured by pulse height on anode strips only. The gas mixture was Ar/CO_2 (70%/30%). All measurements have been performed with ^{55}Fe source, and up to voltages at which fluctuation of current become prominent.

development. There is also a reduced internal detector capacitance due to the large aspect ratio. In addition, since PMMA has a relatively low surface resistivity (10^{14} Ω/❐) compared with Kapton (10^{16} Ω/❐), it is expected that the gain decease due to event rate, and gain instabilities, will be less. Our first measurements yield a very promising performance: high gain, good energy resolution (17 % of FWHM), and good time stability.

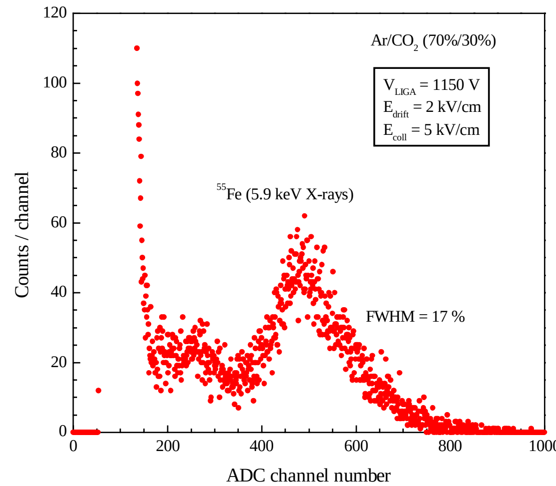

Figure 4: Pulse height spectrum for ^{55}Fe source obtained using a GEM-like LIGA device of 350µm thickness. The FWHM is 17.

Acknowledgments

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References

[1] A. Oed, "Position-sensitive detector with microstrip anode for electron multiplication with gases," Nucl. Instr. Meth., A 263, pp. 351-359, 1988.

[2] F. Bartol, M. Bordessoule, G. Chaplier, M. Lemonnier and S. Megtert, "The C.A.T. pixel proportional gas counter detector," J. Phys. III France, vol. 6, pp. 337-347, 1996.

[3] F. Sauli, "GEM: A new concept for electron amplification in gas detectors," Nucl. Instr. Meth., A 386, pp. 531-534, 1997.

[4] H.S. Cho, J. Kadyk, S.H. Han, W.S. Hong, V. Perez-Mendez, W. Wenzel, K. Pitts, M.D. Martin and J.B. Hutchins," GEM: Performance and aging tests, IEEE Trans. Nucl. Sci., vol. 46, no. 3, pp. 306-311, 1999.

[5] CXRL toolset, University of Wisconsin.

[6] S. Bachmann, A. Bressan, L. Ropelewski, F. Sauli, A. Sharma, and D. Mormann, "Charge amplification and transfer processes in the gas electron multiplier" CERN-EP/99-48, December, 1999.

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Principal investigator: Keith H. Jackson, Materials Sciences Division, Ernest Orlando Lawrence Berkeley National Laboratory. Email: KHJackson@lbl.gov. Telephone: 510-486-6894.